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Energy behaviours as promoters of energy efficiency: A 21st century review

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ABSTRACT

Energy behaviours represent a significant untapped potential for the increase of end-use energy efficiency in buildings. Although energy behaviours are a major determinant of energy use in buildings, energy savings potential due to behaviour are usually neglected, albeit being referred to be as high as those from technological solutions.

This paper presents a review of recent literature on energy behaviours in order to recognise recent trends, quantify energy behaviours potential savings, characterise energy behaviour modelling strategies and identify potential research gaps.

Energy behaviour research is vast and has been essentially focused on the residential sector, striving to establish behaviour determinants and the best strategies and instruments to promote more efficient energy behaviours. Potential savings of energy behaviours are referred to reach 20%, but values differ up to 100% between experiences and additional studies to quantify behavioural savings are needed, in particular by using standard quantification techniques.

Different modelling techniques have been used to model energy behaviours: qualitative approaches from the social sciences trying to interpret behaviour, here named energy behaviour frameworks; quantitative approaches from the engineering and economics that quantify energy consumption, here designated by energy models; and hybrid approaches that are considered the most relevant since they integrate multiple dimensions of energy behaviours, here referred as energy behaviour modelling.

Energy behaviours have a crucial role in promoting energy efficiency, but energy behaviours characteristics and complexity create several research challenges that must be overcome so energy behaviours may be properly valorised and integrated in the energy policy context.

Contents

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1. Introduction

Energy efficiency is recognised as an essential strategy in energy and climate change mitigation policies. The benefits of using energy more efficiently include not only reduced greenhouse gases emissions and local air pollution, but also reduced investments in energy infrastructures, lower fossil fuels dependency, increased competitiveness and improved consumer welfare [1].

Globally, energy efficiency levels have improved in the last years. In general, between 1990 and 2005 all OECD countries reduced their aggregate final energy intensity values, through strong efficiency improvements in all sectors of the economy, including the introduction of modern, efficient technologies and processes [2]. As a result, energy savings of 15% and carbon dioxide (CO_2) avoided emissions of 14% were achieved in 2005 [2]. However, despite this progress, energy efficiency gains were much lower than in the previous decades, if 70s to the 90s are taken as references [1,2]. Trying to explain this fact, the International Energy Agency (IEA) admitted that "changes caused by the oil price shocks in the 1970s and the resulting energy policies did considerably more to control growth in energy demand and reduced CO_2 emissions than the energy efficiency and climate policies implemented since the 1990s" [2]. Nevertheless, energy efficiency is acknowledged as an indispensable energy policy strategy, and during the G8 Summit in 2008 the IEA presented 25 energy efficiency measures that, if implemented globally, could save one-fifth of global energy-related CO_2 emissions by 2030, ranging from various areas such as buildings, appliances, lighting, transport, industry and power utilities [3].

At an European level, the European Union (EU) assumes that even though energy efficiency has improved considerably in recent years, it is still technically and economically feasible to progress further by using different strategies across all activity sectors [4]. For example, these strategies include retrofitting walls and roof insulation in residential buildings, improved energy management systems in commercial buildings, equipments replacement in manufacturing industry, or changing modes of transportation [4]. However, the European Union identifies buildings as the most promising target to improve energy efficiency and quantifies a significant energy saving potential associated with infrastructural and equipment investments (27% in the residential and 30% in the services sector) [4]. Nevertheless, although occupant behaviour is a major determinant of energy use in buildings, energy savings potential due to behaviour are usually neglected [5], albeit being referred to be as significant as those from technological solutions [6,7]. Indeed, there is a critical lack of characterisation and systematisation of behavioural factors as promoters of energy efficiency, and the possible leverage of policies over these is poorly understood [5].

This paper aims to characterise recent trends on energy behaviour research in order to establish potential research gaps, quantify energy behaviours potential savings and review recent strategies used to modelling energy behaviours. Due to the extensive literature on energy behaviours, the review has been restricted to papers published in scientific journals published during the 21st century. The main studies found on these topics are analysed and specific details are emphasised. Finally, a critical analysis and research recommendations are made.

In this setting, some preliminary terminology clarifications are required. First, for the purpose of this study, energy behaviours are those leading to end-use energy consumption. Thus, when referring to energy behaviours there are always two implicit dimensions: the behaviour in itself and the associated energy consumption, in which the second is a consequence from the first and quantifies it. Therefore, the energy consumption may be generated by the use of technologies, the purchase or the adoption of new technologies, or the users aspirations or various interrelationships between these [8]. While the adoption of new technologies relate to investment behaviours, the regular use of technologies are related with habitual behaviours. Habitual behaviours are automatic and routine behaviours through which individuals repeat and do things automatically without conscientiously weighting the pros and cons [9,10]. Although habitual behaviours are functional, they may deliver sub-optimal results in what energy efficiency concerns [9]. In the scope of this study only the use of technologies point of view will be considered, which implies a stronger emphasis on habitual behaviours perspective.

Furthermore, it is important to discuss the difference between energy efficiency and energy conservation in the context of energy behaviours. The terms energy efficiency and energy conservation are often overlapped in energy research and policy making contexts [11]. Furthermore, during this review both terms were found when referring to energy behaviours contexts (e.g. [8,10,12–18]). However, some authors argue that the term energy efficiency should not be used when referring to energy behaviours [11]. They stress that while energy efficiency refers to the adoption of specific technologies that reduce the overall energy consumption without changing the relevant behaviours and achieving the maximum services obtainable (such as heating, lighting, cooling, mobility), energy conservation is merely a change in consumers behaviour that leads to energy savings. This study will focus on the strict energy efficiency definition of reducing the final energy consumed while achieving the maximum energy services possible. Therefore, energy efficiency may not be achieved only by the change of technologies, but also by the way they are used, which are related to energy behaviours. Accordingly, in this study the term energy efficiency will be used in an energy behaviour context.

The paper is organised as follows. In Section 2 an overview on recent energy behaviours research is presented, drawing attention to the most important studies, results and research gaps. Section 3 presents existing studies and estimates on potential savings of energy behaviours and discusses the main results. In Section 4 several approaches used for modelling energy behaviours are explored and characterised and, finally, at Section 5 a critical analysis and the main conclusions of this review are presented.

2. Energy behaviours research

Most of the research on energy behaviours has been essentially focused on the residential sector. Energy behaviour studies in the residential sector are predominantly field experiments testing instruments to promote more efficient energy behaviours (e.g. [19–29]) and trying to establish the behavioural determinants for energy use (e.g. [13–18,30,31]).

The majority of energy behaviour studies in this last decade has been dominated by the psychology research. One of the most relevant publications on residential energy behaviours is due to Steg and Vlek [32], which has its origins on environmental psychology. It consists on a comprehensive review that systematises the factors underlying pro-environmental behaviour in the residential sector and the type of interventions to encourage this type of behaviour. The authors begin by identifying motivational factors, contextual factors and habitual behaviour as the most important factors in environmental behaviour. Motivations, from an individual perspective, lead people to engage in environmental behaviour and are categorised into perceived costs and benefits, moral and normative concerns, and affection. The first motivation considers that individuals weigh the pros and cons, making rational choices in order to maximise their benefits. The second is related to the valuation of environmental beliefs and environmental concerns, the moral obligation to act pro-environmentally

and the influence of social norms on behaviour. Finally, the third make use of affective and symbolic factors to explain environmental behaviour. Further, the authors underline that these different perspectives are not mutually exclusive and are all useful to predict environmental behaviours. However, being traditionally focused on the individual perspective, environmental psychology often fails to examine the contextual influence on environmental behaviours. In fact, these authors also stress that many contextual factors may facilitate or constrain environmental behaviours and influence individual motivations. Furthermore, rather than being preceded by pure rational processes, behaviour is frequently habitual and guided by automated cognitive processes [15,32]. Habits are automated goal-based behaviours that tend to be repeated in certain circumstances when their outcomes are generally satisfactory, and often involve misperceptions and selective attention on information that reinforces the habitual behaviour [32].

Strategies for promoting more efficient energy behaviours have been differently systematised by several authors. For example, a categorisation has been made as antecedent or consequence strategies [12,32]. While antecedent interventions are designed to change factors that precede behaviour, consequence strategies focus at changing the consequences following behaviour, based on the assumption that more efficient energy behaviours will become more attractive when positive consequences are attached to it. Antecedent interventions include commitment (promise to change behaviour, usually linked to a quantified goal), goal setting (a target is quantified), information (it is the most common strategy and is used to increase awareness) – which are provided using workshops, mass media campaigns or tailored information, and modelling (providing examples of recommended behaviours). Consequence strategies may comprise feedback (providing information on energy consumption), and rewards (particularly monetary). Another classification is made by [32] in informational and structural strategies. Informational strategies target the motivational factors and are designed to change perceptions, motivations, knowledge and norms, without actually changing the external context in which choices are made. Examples include providing information, persuasion (to influence attitudes and reinforce commitment), social support and role models (to strengthen social norms). Structural strategies aim to change the contextual factors of behaviours, e.g., changing the costs and benefits of alternatives or legal instruments. Overall, the intervention effectiveness increases with a preliminary clear identification of the behaviour causal factors and barriers, followed by the use of a combination of the most effective strategies [12,32].

It is notorious the difference in approaches used by diverse disciplines for encouraging more efficient energy behaviours. As previously analysed, while environmental psychology addresses mainly behavioural factors, economics assumes individuals as fully rational (or almost), that is making rational decisions and actions [33,34]. Therefore, economic strategies consist of correcting market failures, by providing information (e.g. audits, labels), securing capital for investments (e.g. grants, loans, energy services companies contracts) and supporting research, development and dissemination of energy-efficient solutions [33]. In turn, whereas psychology and economics focus on the individual behaviour, sociology proposes that energy demand is not only originated by the individual, but it is also a result of a social construct and therefore strategies to be effective must consider this perspective [33,34]. Examples include collective actions, social learning, and sociotechnical networks [33]. However, this perspective is also recognised by the environmental psychology research when it stresses the importance of considering public participation strategies to gather people attention, gain their commitment and increase their involvement [32]. These different approaches result from the underlying behavioural frameworks and will be addressed and developed further on in this paper.

Traditionally, strategies for promoting more efficient energy behaviours have been used by energy policies, demand side management and behavioural change programmes, promoted by national and local authorities, utilities, energy agencies and consumer associations. Although considerable investments have been done in these programmes in the last decades, more significant behavioural changes ought to be achieved. Two recent studies carried out an assessment of behavioural change programmes [10,33]. Both studies reviewed hundreds of European initiatives and projects to identify success factors. One of the most important results is that in order to promote the interventions effectiveness, planners knowledge on theoretical background must be increased and "adequate time and consideration must be given to identify the approaches, instruments and programmes most likely to yield the desired outcomes" [10] – which is in accordance with [12,32] conclusions. Furthermore, interventions must be designed according to consumer profiles (using market segmentation) and target the easiest behaviours to change with the greatest impacts. Following these results [35] presents a planning methodology for the systematic development of interventions to promote more efficient energy behaviours, named intervention mapping approach. In simple terms, this method provides a systematic tool that help planners to identify interventions behavioural change objectives, to select the most appropriate theoretical background and methods that have been proven to effectively generate the desired behavioural changes. It involves the following phases: needs assessment, programme objectives, methods and applications, programme development, planning for programme implementation and assessment.

However, during this last decade, energy behaviour research has substantially focused its attention on a specific strategy for promoting more efficient energy behaviours, which are feedback mechanisms. Feedback consists in providing information on energy consumption and is seen as an essential strategy to rematerialise energy consumption, contributing to raise awareness and encouraging individuals to have more efficient energy behaviours [9,20,36]. Feedback is often categorised as direct, indirect and inadvertent, depending on how the information is disseminated, on the type, quality and quantity of data presentation, and on interaction and control by the energy user [37]. There are several field experiments testing particular feedback features on energy consumption, such as the provision of tailored information and goal setting [19], or the use of in-home displays [20,23,25,36,38,39]. In one of the most important publications on this topic, [9] reviews the effects of feedback on electricity consumption and on consumers' reactions and attitudes, as well as feedback preferences. This author stressed that successful feedback has to capture the consumers' attention, draw a close link between specific actions and their effects and activate various motives that may appeal to different consumer groups. Relevant features of feedback may determine its effectiveness and those include frequency, duration, content, breakdown, medium and way of presentation, comparisons, and combination with other instruments. Yet, the most valued features by household consumers are presentation of costs over a period of time, appliance-specific breakdown, historical comparison and presentation using computerised and interactive tools. The most important conclusion is that there is not "the" perfect feedback for everybody and feedback should be tailored according to each group norms and motivations, which was also supported by [19,10]. Also important, feedback preferences may vary according to regional differences, and since existent studies were mainly developed in North America, central and northern Europe, it is relevant to conduct feedback studies in regions with different social contexts.

Nevertheless, despite the significant existing background knowledge on energy behaviours in the residential sector, behavioural studies on determinants or strategies are almost inexistent for other type of buildings such as services. Most of the studies on services focus on common barriers to energy efficiency and energy use determinants (e.g. [40–44]). In fact, only [45] addressed behavioural aspects in services, evaluating feedback and peer education as instruments for promoting more efficient energy behaviours in university buildings. Although this study is limited by the sample type and size, its results are consistent with the residential experience and significant energy savings were achieved. Further, only one study compared energy behaviour in both environments [46], particularly concerning differences in comfort and use of thermostats. Accordingly, there is a noteworthy unexplored line of research associated with energy behaviours in services buildings, as well as comparing energy behaviours in both types of buildings.

3. Potential savings of energy behaviours

Although there is a broad research on energy behaviours, just a small number of studies quantifies how much energy behaviours accounts for in terms of potential energy savings or CO_2 emissions. In the context of this review only nine studies were found for residential buildings and three for services buildings (Table 1).

The studies on residential buildings are field experiments [19,23,47,48], simulations [49,50], and reviews of existing experiments [7,9,10,51]. They vary substantially in geographic area, scope, intervention type, scale of study and energy policy context. However, there is a significant number of studies that focus on feedback effects on behaviour, by quantifying its energy savings effects [9,19,23,51]. Depending on the studies contexts, huge differences in energy savings can be encountered. For example, at the European level, the review of behavioural change programmes concludes that behavioural savings potential could reach approximately 20% [10], but in its world review [7] concludes that results may differ up to 100% between case studies. As a result, there are severe limitations to generalise energy savings and CO_2 emissions. Furthermore, experiences usually combine behaviour change with equipment replacement [47], therefore making impossible the exclusive quantification of the behavioural component. Finally, studies that quantify potential behaviour savings at service buildings are scarce. Three studies were found, where two consist of audits [52,53] and one tests a feedback strategy [54]. For example, [53] studies user behaviours in offices, schools and medical buildings in particular turning off devices at night or enabling power management of office equipments. Although they have not calculated direct savings, they conclude that less than 50% of the equipments are turned off, and less than 10% of desktop computers enter low power mode, while 53% successfully initiate power management in monitors. These results are in accordance with [52] findings, indicating clear opportunities not only for energy management but also for behavioural change in services buildings.

However, even though there are limitations to generalise energy potential savings from existing studies, there is a reference study based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [7], which synthesises the results from several experiences around the world. Their authors recognise the difficulty to quantify non-technological factors and that this weakness has been limiting the research in this field. Furthermore, they admit that there is a critical lack of understanding and characterisation of behavioural options to reduce CO_2 emissions (and consequently energy use) of residential and commercial buildings. The authors recommend that these factors, and their interconnections, including those with technological ones, should be mapped and understood, as well as integrated into model and scenario analyses. Nevertheless, they are the first to admit that energy savings through behavioural factors can be as high as those from technological ones, therefore reinforcing their role in energy efficiency.

4. Energy behaviours modelling

Modelling is a central tool to modern science and policy making, since it helps to explain reality and systems functioning (e.g. technological, biophysical and economical), thus informing the thinking and guiding decisions [55]. In energy efficiency, modelling is usually utilised to forecast energy demand, predict the adoption of new technologies and estimate the impacts of energy efficiency programmes.

For the purpose of this review, three categorisations on energy behaviour models will be used that attempt to accurately illustrate the literature published under this topic: (1) energy behaviour frameworks that include theories and explanatory models of energy behaviours; (2) energy modelling that quantifies energy use and (3) energy behaviour modelling that comprises quantitative and qualitative approaches used for forecasting behaviours. Again, energy behaviour models have been essentially developed for the residential sector, although some energy models focused on the thermal behaviour of buildings were developed both for residential and services buildings.

4.1. Energy behaviours frameworks

The most comprehensive review on energy behaviour frameworks in the last decade is presented by Wilson and Dowlatabadi [34]. The authors focus on the point of view of residential energy use and explore the most relevant social theories that determine individual decision making:

- utility-based decision and behavioural economics;
- technology adoption and attitude-based;
- decision theories in social and environmental psychology; and
- sociological theories that cover the influence of social context in decision making.

4.1.1. Utility-based decision and behavioural economics

The foundation of utility-based decision models is the microeconomic theory of utility maximisation given certain preferences. Consumers are assumed to behave rationally, in the sense that they maximise utility given budget constraints and that their preferences are perfectly well-organised, recognised, stable and consistent. This theory has been used, for example, in eliciting the consumer preferences concerning energy efficient appliances or the choice of electricity suppliers in deregulated markets. However, there is evidence that consumers do not always make consistent rational decisions, even if they are given perfect information. Some examples of inconsistencies include [34,56]:

- *Time inconsistency*. Individuals do not make decisions in a time consistent manner using constant discount rates. Instead, depending on the situation, they make different decisions with different discount rates associated.
- *Bounded rationality and heuristic decision making*. Consumers are rational but face cognitive constraints in processing information. Therefore, consumers tend to use a wide range of heuristics (simple decision rules) to reduce cognitive requirements.
- *Framing and reference dependence*. Consumers' decisions are influenced by the way information is presented to them. Different results may be obtained simply by framing the decision as a choice between losses or gains. Furthermore, when making a decision,

Table 1
Potential behavioural energy savings and reduced emissions in residential and services buildings.

Buildings	Region	Approach	Energy savings or reduced emissions	Reference
Residential	World	Review of non-technological factors influence on energy consumption and carbon emissions in buildings (80 studies)	Approximately 29% of the projected baseline emissions by 2020 can be avoided	[7]
	USA, Japan, Denmark, Finland, Germany, the Netherlands, Sweden, Switzerland, UK	Feedback review study (26 projects)	Electricity savings range from 1.1% to over 20%. Usual savings are between 5% and 12%	[9]
	USA	Use of available technologies and non-business travel actions combined, without reducing the household well-being	123 Mton carbon/year within 10 years representing 20% of residential buildings direct emissions or 7.4% of USA emissions	[50]
	North America and Japan	Feedback review paper on 12 utility pilot programmes, in particular, in-house displays feedback	Electricity savings range from 7% without an electricity prepayment system, to 14% with that scheme	[51]
	Japan	Feedback study using an on-line residential energy consumption information system	9% reduction in power consumption	[23]
	China	Energy-saving education strategy in 124 households	More than 10% electricity use (this contributed as much as insulation measures to reduce CO_2 emissions during 40 years)	[48]
	Kuwait	Simulated occupancy patterns using ENERWIN software	Behavioural change concerning lighting patterns could save 29% (37 MWh/year) and AC thermostats adjustments could save around 50 MWh/year	[49]
	Europe	Review on 100 behavioural intervention projects on 11 European countries	Savings potentials may reach 20%	[10]
		Replacement the appliances by the most efficient ones and reducing the stand-by consumption. Sample: 1300 households in 12 countries	Electricity savings of 50% (165 TWh/year; 72 Mton CO_2 emission savings) EU27: 268 TWh/year and avoided emissions of 116 Mton CO_2/year	[47]
	The Netherlands	Feedback strategy using an internet-based tool combined with tailored information, goal setting, and tailored feedback	5.1% energy savings	[19]
Services	South Africa and Botswana	Energy audits in commercial buildings	Electricity savings of 56% trough lighting and equipments turned off in non-working hours	[52]
	USA	Feedback strategy using an energy information system at four commercial enterprises and university campuses	18–35% in energy use	[54]
		Energy audits in commercial buildings to determine turn-off rates and power mode rates for office equipments	Although no direct savings were calculated, only less than 50% of the equipments were turned off and less than 10% of desktop computers entered low power mode, while 53% of monitors initiated power management	[53]

instead of searching and processing all relevant information, consumers tend to “anchor” on predetermined information, usually the status quo (the reference point with respect to which gains and losses are evaluated).

4.1.2. Technology adoption and attitude based models

Technology adoption and diffusion model aim to explain how and why innovations, such as energy efficient technologies, occur and are disseminated. It is applicable to situations where social networks and technological attributes are the critical factors. This model assumes that there is a decision process with several phases that guides a change from knowledge to the change in behaviour (namely: knowledge, persuasion, decision, implementation, confirmation). Furthermore, feedback in the later stages of the decision process interacts with the previous stages; for example, internal feedback reinforces attitudes, resolves dissonance and change behaviour, while external feedback changes affection and preliminary conditions. The adopters and innovations characteristics not only influence how knowledge and attitudes are formed, but also help to explain the different adoption rates. For instance, the following features of an innovation explain mostly of its adoption rates: relative advantage over the common practice; compatibility with existing needs, norms and behaviours; skills required to adopt it; possibility of testing it prior to the adoption; and if it is highly visible to potential adopters. According to this model adopters are usually categorised into innovators, early adopters, early majority, late majority and laggards [57]. However, although the diffusion of innovations theory is the dominant framework when explaining the adoption of innovations it is limited by its assumptions. For example, technologies and behaviours are not adopted simply through awareness and favourable attitudes, and contextual factors are very important when explaining behaviours and innovations adoption.

Associated with this model, other attitude and belief-based behaviour models try to explain how cognition leads to action, namely the cognitive dissonance, the theory of planned behaviour and self-efficacy, feedback, and reinforcement. Individuals struggle to be coherent and try to reduce their internal inconsistencies between knowledge, attitudes, and actions, thus progressively having more consistent behaviours. The theory of planned behaviour, built from the theory of reasoned action, is a linear decision model that considers attitudes to be formed both from the individuals’ beliefs about behaviour as well as an evaluation of its outcomes (almost like the bounded rationality approach). In conjunction with normative beliefs about what peers might think of the behaviour, these attitudes lead to an intention to act, which in

turn predicts behaviour. Self-efficacy may determine whether an individual attempts and persists with a given task and is influenced by past experience, the example of others, and perceived skills. In fact, experience has shown that reinforcing self-efficacy by setting achievable goals and providing feedback supports energy efficiency [34].

A field experiment is presented herein to illustrate the social cognitive theory in an energy behaviours context [58]. A sample of electricity consumers was used to understand the (lack of) energy saving efforts of households. The study concluded that households' electricity consumption depends on both structural and motivational factors. In turn, electricity saving efforts depend on the strength of internalised norms or self-expectations and on self-efficacy related factors. Furthermore, there are predictable patterns of interaction among household members that influence their electricity consumption.

4.1.3. Social and environmental psychology

As already mentioned, social and environmental psychology has been comprehensively researching energy behaviours. An early line of research emphasises the importance of information and incentives on energy behaviours, but experience demonstrated that this was not effective. Psychology then shifted its attention to the role of constructs framed by environmental concerns, in particular values, attitudes and norms. Moreover, social psychology research has been testing the existence of socioeconomic (e.g. income, education and household composition) and psychological correlations in residential energy use (e.g. [30]). Although no strong correlation between these two factors has been found, these studies stress that behaviours need to be distinguished according to several features, specifically their psychological characteristics, frequency, repetitiveness, cost and associated amenity losses [34].

The value-belief-norm (VBN) theory proposes a causality relation between the personality, specific beliefs about the consequences and responsibilities of particular actions, attitudes and personal and social norms. For new norms and considerations to enter the decision-making process, a conscious decision needs to be taken during a process called norm activation, which may happen, for example, due to a conflict between norms. However, decision models that exclude contextual factors often fail to adequately explain energy behaviours when it involves high-effort, high-cost and high-involvement decisions. Hence, context was incorporated in the attitude-behaviour-external conditions (ABC) model. In this model, attitudes lead to behaviour change only if contextual variables (physical, financial, legal, or social) provide either incentives or disincentives.

Based on the preceding models [34] presents an integrative pro-environmental behaviour model that distinguishes personal and contextual domains while recognising interactions between them. Whereas the personal domain comprises habits, current practice, past experience and attitudes, the contextual domain focus on both individual and collective variables (e.g. technical skills, know-how, social norms and expectations).

4.1.4. The social construction of decision making

On the opposite perspective of the previous models, sociology approaches generally argue that energy use is not a consequence from individual choices, but it actually results from the social context. Needs, attitudes, and expectations are not individual in nature but are part of a complex relationship between social norms and relations, technologies, infrastructures and institutions. Individuals do not make decisions to consume energy or the resources that provide energy. Instead, energy provides useful services that enable normal and socially acceptable activities to be carried out as part of the daily life. The demand for energy is therefore the result of a long and complex process and not consequence of immediate individual decisions.

Focusing on the energy efficiency gap, a similar line of research highlights the ubiquity of energy use in domestic routines, since habitual home activities such as cooking, cleaning or entertainment consume energy. In addition, it stresses that individual choices are usually limited and constrained, due to the limited supply of technologies, individual skills and knowledge or the nature of contractors. Further, individuals are daily exposed to a non-conservation message through marketing strategies, and for a long time energy efficiency has not been an attractive topic.

Finally, a perspective on the social organisation of residential energy analyses the household (rather than the individual) level, capturing normative and routine behaviour and recognising domestic rules. Social characteristics such as the number of household occupants, their age, gender or income may be used to create meaningful sociocultural units, enabling a richer analysis of the role of family relations and other aspects of energy use. Controlling the differences in building design and technologies, social interactions within households may provide patterns of energy use over time that may explain the variability among households (such as the approaches used by [59–61] illustrate).

4.1.5. Energy behaviour frameworks final remarks

Complementarily to [34] review previously analysed, [62] presents behaviour models on consumer choices with respect to energy efficiency products for a marketing and policy contribution. It explores several energy frameworks from the point of view of the consumption process components:

- consumer choice – procedural rationality, behaviour economics and hierarchy of needs theories;
- needs and desires – personality, control, self-discrepancy, pro-social behaviour, perceived consumer effectiveness, collective action dilemma, willingness to pay, and value belief norm theories;
- learning – cognitive consistency, balance, consistency, cognitive dissonance, and relational discrepancy theories;
- social network – social exchange, behaviour economic and behaviour perspective model theories;
- buying – rational choice, theory of reasoned action, theory of planned behaviour, hierarchy of effects, and innovation decision theories;
- categorisation of consumers – behavioural economics and diffusion theories;
- product attributes and categorisation – diffusion theory.

Although most of the models have been already presented earlier in this review, some different theories are indicated that explain specific features of the consumption process. However, the aim of this paper is to explore energy behaviours frameworks from the energy use perspective and not from the purchase viewpoint. Accordingly, for further developments of consumption frameworks see [62].

As a closing remark, the models presented vary widely in their basic assumptions, independent variables, structure and scale. While economics, behavioural and social psychology, and technology diffusion focus on the individual as decision maker, sociology questions the relevance of individually framed decision theories and highlights the social and technological construction of behaviour. However, [34] emphasises that residential energy use is characterised by a wide range of decision types and contexts, as well as psychological and contextual influences on behaviour, and therefore all theories are relevant to explain residential energy use. Building on these conclusions, [8] proposes an integrated energy behaviour model by bridging research traditions centred on the

individual and those centred on wider social and technological constructs. This model assumes that behaviour is influenced by the interactions between cognitive norms (e.g. beliefs, understandings), energy practices (e.g. activities, processes) and the material culture (e.g. technologies, buildings). Its four main characteristics are: it is change-oriented rather than deterministic, since it proposes social, environmental and economic forces, but do not determine persons cognitive norms, practices and material cultures; it accounts for the context through its modelling of the interactions between the three core components of behaviour, and between these and wider societal and structural influences; it is particularly designed to characterise variability in behaviours, enabling segmentation of the population in terms of different clusters of similar patterns of norms, practices and/or material culture; and it works at different scales and in different sectors, being applicable to understanding a individual household, a business, neighbourhoods, industries or regions. Although being a conceptual model, it was developed from a case study using a multi-disciplinary research design approach.

4.2. Energy modelling

Energy models can be found on the exclusive quantitative side of energy behaviour modelling spectrum. Energy modelling is used for energy consumption quantification in policy decision support contexts, such as macro-scale regional and national energy supply assessments or micro-scale engineering approaches, such as simulation of technologies use or thermal behaviour of buildings.

A comprehensive review on the techniques utilised for modelling energy consumption in the residential sector is presented in [63,64]. Energy models are grouped into top-down and bottom-up. Top-down approaches determine long-term trends on energy consumption primarily for macro supply analysis, based on aggregated and widely available historical energy consumption information and input variables (e.g. gross domestic product, employment rates, price indices, climatic conditions, housing construction/demolition rates, income, estimates of appliance ownership). They consider the residential sector as a system and do not distinguish individual energy consumption uses. These models comprise econometric, technological and combined techniques. While econometric top-down models seek to establish the connection between the energy use and economic variables, the technological approach focus on other factors, such as the housing stock characteristics, appliances ownership, technological and structural trends. In contrast, bottom-up approaches employ as input data the energy consumption of individual end-uses, individual buildings, or groups of buildings and extrapolate this information to represent the region or nation based on the representative weight of the modelled sample. Bottom-up models include statistical and engineering methods. Based on historical information, the first use regression analysis to attribute energy consumption to particular end-uses and then estimate the energy consumption of dwellings that are representative of the residential stock. The engineering techniques are used to explicitly calculate energy consumption of end-uses based on detailed descriptions of a representative set of buildings. For instance, they combine building physical variables, such as the efficiency of space heating systems and their characteristics, the areas of the different dwelling elements along with their thermal characteristics, internal temperatures and heating patterns, ventilation rates, energy consumption of appliances, number of occupants, and external temperatures, to estimate the energy consumption of a representative sample of buildings.

While top-down approaches are referred to allowing for long term forecasting using simple, aggregated, and widely available information, they lack detail regarding the energy consumption of individual uses and therefore miss to identify key areas for energy efficiency improvement. Furthermore, by relying on historical data they fail to adequately model discontinuities due to advances in technology. On the contrary, bottom-up approaches determine energy end-uses, although using different techniques (statistical ones determine typical uses and engineering ones use simulations). Bottom-up statistical models require large samples and engineering models are computationally intensive. Hence, these approaches have strengths and weaknesses when modelling energy consumption that must be considered when designing an energy modelling research. For the purpose of this paper it is important to emphasise that these types of models often fail to adequately deal with socio-technical influences on energy consumption, specifically behavioural ones. For example, how householders use domestic appliances or how they react to changes in the dwelling as a result of energy performance measures. Nonetheless, specific micro-scale engineering models analyse occupants' behaviour influence on the buildings thermal behaviour. Examples include, for residential buildings, the occupants perception on thermal comfort [65,66], the control of indoor environments [49,67,68], the influence of socio-economic parameters on cooling [69], or the influence of thermal comfort on the buildings energy consumption and efficiency [70–73]. Other micro-scale engineering approaches seek to establish end use energy profiles, such as laundry and dishwashing [74], or to develop load pattern recognition methodologies [75]. For services buildings the micro-scale engineering models studies are similar to residential buildings. The majority focus on thermal comfort [76–80], natural ventilation [81,82], windows control [69,83], or even modelling towards zero-energy buildings [84]. Usually they pre-assume occupants behaviour based on statistical models (such as [85]), although some compare the behavioural assumptions with reality through qualitative methods (such as [83]). Equally important, modelling strategies have been developed to simulate energy consumption in buildings services, such as the agent based approach [86]. Finally, the only study that compares residential and services buildings is focused on thermal comfort, comparing it between homes and office rooms [46].

4.3. Energy behaviours modelling

Last but not least, energy behaviour modelling integrates quantitative and qualitative approaches for predicting behaviours and establishing user profiles. The literature review exposed only two, but important, lines of research that integrate behaviours and energy consumption to provide consumer profiles using different strategies.

One of the most interesting profiling approaches integrates qualitative research on households' behaviour and habits with quantitative analysis and modelling of energy demand [59,60]. It is based on a time-geographic diary approach used to establish the daily activities and their connections with energy use. Profiles are generated from a comparison between a detailed data set on the time for everyday activities in households and electricity measurements, and different activity patterns are identified and connected to different household categories. This modelling technique generates individualised load profiles, for each household member, instead of using the household as the smallest analysis unit. It has a great potential on providing insights on how everyday activities contribute to energy use. However, it is based on a very time and resource consuming information process, which consists in written time diaries that are usually inexistent and difficult to obtain. A similar integrative approach combines an energy model, a software tool and interviews for revealing consumer preferences in relation to different energy behaviours [87]. In this case, a software tool is used to provide users with a detailed accounting of how much energy they use and comparing their energy consumption with a list of energy behaviours. The results revealed that different

user profiles can emerge according to their energy consumption, their energy savings potential and their willingness to behaviour change.

A more quantitative approach on energy behaviour modelling consists of extracting energy consumption patterns through data analysis techniques (data mining) in order to establish energy use profiles. Data mining is commonly used for establishing patterns of energy consumption (for example, weekly energy use patterns in buildings [88]). However, by organising similar buildings into groups based on influencing factors unrelated to user behaviour (e.g. climate, building characteristics, services and operations) [61] determines different end-use loads profiles as a result of various energy behaviours. Even though this approach establishes different energy behaviours profiles, it requires a large building sample, which is typically very complex to attain.

5. Critical analysis

This work explored peer-reviewed publications on the topic energy behaviours, in particular end-use energy behaviours in residential and services buildings and modelling behaviours approaches. The main studies found on these topics were analysed and relevant details were emphasised.

In summary, energy behaviours are hugely complex, shaped by many factors, not only individual but also contextual. Due to this complexity, they are usually studied using fragmented and disciplinary studies from a wide range of thematic areas such as psychology, sociology, economics and engineering. While the social sciences focus on understanding and explaining energy behaviours, engineering and more technological approaches quantify energy consumption as a support for decision and policy making. However, each approach is limited by its own assumptions and often neglects important energy behavioural components. Therefore, energy behaviour studies require an integration of disciplines through interdisciplinary approaches, in particular, by bringing engineering and social sciences together. Furthermore, while the social sciences use mostly qualitative methods (such as interviews, focus groups and surveys [89]), engineering use quantitative methods (e.g. simulations, load quantification). Hence, the quantification of behaviours, and, in particular, energy savings potential, must consider both approaches: qualitative and quantitative.

However, interdisciplinary energy behaviours research is resource intensive. Due to the complexity mentioned above, interdisciplinary knowledge is required to adequately address energy behaviour issues. As a result, these studies require specialised and multidisciplinary teams that will need to establish, not only a common theoretical background, but also a lexicon framework. Besides their great demand concerning human labour, energy behaviours studies are time and equipments consuming, particularly concerning energy monitoring equipment. Moreover, energy behaviours research requires the participation of individuals that will compose the study sample, which are not usually willing to participate (namely due to privacy issues), neither for a long time period. This raises clear research design challenges and as a result, research design habitually includes field experiments with small samples and limited time scales (named quasi-experiments). However, this limits significantly the application and generalisation of the results of energy behaviours research to the overall reality.

The complexity of energy behaviours research is also associated with the intrinsic shifting and inconsistent characteristics of behaviours and the high variability of energy consumption in buildings. Energy behaviours are not static, they change along accumulated experiences, and they are often inconsistent. This increases research difficulties, and therefore it must be designed in order to minimise this effect. Moreover, the energy consumption in buildings is rather variable and different patterns and profiles may be extracted at different aggregation levels and at different time scales. Considering this review results, context may provide the missing information to interpret and modelling energy behaviours.

In general, research on energy behaviours has been essentially focused on the residential sector. Only few studies centred their attention on behaviours in services buildings and, to the authors' knowledge, only one study compared energy behaviour in both types of buildings. Therefore, there is a noteworthy unexplored line of research associated with energy behaviours in services buildings, and in particular, comparing them within both environments.

Although energy behaviour studies in the residential sector in the last decade have been predominantly field experiments testing instruments to promote more efficient energy behaviours and trying to establish the behavioural determinants for energy use, there were also some comprehensive review studies that brought essential systematisation to this topic. The majority of behavioural studies have been dominated by the social sciences, in particular, by the environmental psychology. A large share was focused on strategies for promoting energy efficiency, and in particular, feedback mechanisms. Nevertheless, regardless the common agreement that behavioural changes are required to increase energy efficiency levels, and the numerous interventions on behavioural change that were put in place in the last decades, these interventions have been ineffective and have not achieved significant behavioural changes. Effectively, recent assessments concluded that their main failure was due to methodological issues, particularly relating the theoretical background framing, the target segmentation and the overall approach. These are crucial conclusions, not only for behavioural change programmes, but also for energy behaviours research. However, even if there is a broad research on energy behaviours, there are only a small number of studies that quantify how much energy behaviours represent in terms of potential energy savings, or CO_2 emissions reduction, for both residential and services buildings. Depending on various factors, different energy savings were found, and consequently there are severe limitations to generalise energy savings. Nonetheless, energy savings through behaviour are recognised to be as high as those achieved using technological solutions, but the difficulty to quantify behaviour has been limiting the research in this field. It is believed that this also has had energy efficiency policy consequences, since the lack of energy behaviour quantification has limited the integration of this topic in energy efficiency policies, thus reducing their efficacy. Therefore, standard quantification methodologies of energy behaviour are required and research must contribute to it, thus reinforcing the role of behaviours in energy efficiency policies.

As previously mentioned, energy behaviours are studied by different disciplines that range from the social sciences to applied engineering. However, these disciplines have extremely different perspectives on energy behaviours modelling and differ substantially in approach, methodology, objectives and scope. On the one hand, the social sciences approach is more theoretical and conceptual. Social models try to explain, interpret and predict behaviour, through explanatory theories, general frameworks and conceptual models. On the other hand, engineering and more technological disciplines have a more quantitative perspective on modelling, quantifying energy consumption and extracting consumption patterns. For the purpose of this review, three categorisations on energy behaviour models were used: behaviour frameworks that included theories and explanatory models of energy behaviours; energy models that quantified energy use; and behaviour models, that comprised quantitative and qualitative approaches used for establishing energy behaviour profiles. Considering the dual dimensions of energy behaviours, the behaviour in itself and the intrinsic energy consumption, energy behaviour modelling is con-

sidered the most relevant approach in integrating the several behavioural dimensions.

Finally, energy behaviours are going to face future challenges during the ongoing transformation of electric grids into intelligent power grids (smart grids). Smart grids will provide a completely different technological context and therefore they will change the customer–utility relations and raise significant challenges to users and energy behaviours. Although it is expected that smart grids will increase energy awareness levels and encourage more efficient energy behaviours, this technological context is still under research and development, and behavioural research in this context is in its beginning. However, in order to ensure an adequate implementation of smart grids, research on energy behaviours and user involvement must be developed at the same time as this technological framework.

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References

[1] Taylor PG, d'Ortigue OL, Francoeur M, Trudeau N. Final energy use in IEA countries: the role of energy efficiency. Energy Policy 2010;38(11):6463–74.
[2] OECD/IEA. Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis – In support of the G8 Plan of Action. Paris: International Energy Agency/Organisation for Co-operation and Development; 2008. p. 94.
[3] OECD/IEA. Energy Policies of IEA Countries: Portugal 2009 Review. Paris: International Energy Agency/Organisation for Co-operation and Development; 2009. p. 178.
[4] CEC. Communication from the commission – action plan for energy efficiency: realising the potential. Commission of the European Communities; 2006. p. 25.
[5] Levine M, Urge-Vorsatz D, Kornellis B, Geng L, Harvey D, Lang S, et al. Residential and commercial buildings. In: Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press; 2007. p. 338–446.
[6] Jonsson DK, Gustafsson S, Wangel J, Hojer M, Lundqvist P, Svane O. Energy at your service: highlighting energy usage systems in the context of energy efficiency analysis. Energy Efficiency 2010.
[7] Ürge-Vorsatz D, Novikova A, Köppel S, Boza-Kiss B. Bottom-up assessment of potentials and costs of CO_2 emission mitigation in the buildings sector: insights into the missing elements. Energy Efficiency 2009;2(4):293–316.
[8] Stephenson J, Barton B, Carrington G, Gnoth D, Lawson R, Thorsnes P. Energy cultures: a framework for understanding energy behaviours. Energy Policy 2010;38(10):6120–9.
[9] Fischer C. Feedback on household electricity consumption: a tool for saving energy? Energy Efficiency 2008;1(1):79–104.
[10] Gynther L, Mikkonen I, Smits A. Evaluation of European energy behavioural change programmes. Energy Efficiency 2011:1–16.
[11] Oikonomou V, Becchis F, Steg L, Russolillo D. Energy saving and energy efficiency concepts for policy making. Energy Policy 2009;37(11):4787–96.
[12] Abrahamse W, Steg L, Vlek C, Rothengatter T. A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology 2005;25(3):273–91.
[13] Barr S, Gilg AW, Ford N. The household energy gap: examining the divide between habitual- and purchase-related conservation behaviours. Energy Policy 2005;33(11):1425–44.
[14] Ek K, Söderholm P. The devil is in the details: household electricity saving behavior and the role of information. Energy Policy 2010;38(3):1578–87.
[15] Maréchal K. Not irrational but habitual: the importance of behavioural lock-in in energy consumption. Ecological Economics 2010;69(5):1104–14.
[16] Martinsson J, Lundqvist LJ, Sundström A. Energy saving in Swedish households. The (relative) importance of environmental attitudes. Energy Policy 2011;39(9):5182–91.
[17] Nair G, Gustavsson L, Mahapatra K. Factors influencing energy efficiency investments in existing Swedish residential buildings. Energy Policy 2010;38(6):2956–63.
[18] Nässén J, Holmberg J. Quantifying the rebound effects of energy efficiency improvements and energy conserving behaviour in Sweden. Energy Efficiency 2009;2(3):221–31.
[19] Abrahamse W, Steg L, Vlek C, Rothengatter T. The effect of tailored information: goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. Journal of Environmental Psychology 2007;27(4):265–76.
[20] Hargreaves T, Nye M, Burgess J. Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy 2010;38(10):6111–9.
[21] Martiskainen M, Coburn J. The role of information and communication technologies (ICTs) in household energy consumption—prospects for the UK. Energy Efficiency 2010:1–13.
[22] McCalley LT, Midden CJH. Energy conservation through product-integrated feedback: the roles of goal-setting and social orientation. Journal of Economic Psychology 2002;23(5):589–603.
[23] Ueno T, Sano F, Saeki O, Tsuji K. Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data. Applied Energy 2006;83(2):166–83.
[24] van Dam SS, Bakker CA, van Hal JDM. Home energy monitors: impact over the medium-term. Building Research & Information 2010;38(5):458–69.
[25] Willis R, Stewart R, Panuwatwanich K, Jones S, Kyriakides A. Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. Resources, Conservation and Recycling 2010;54(12):1117–27.
[26] Galis V, Gyberg P. Energy behaviour as a collective. Energy Efficiency 2011;4(2):303–19.
[27] Leighty W, Meier A. Accelerated electricity conservation in Juneau, Alaska: a study of household activities that reduced demand 25%. Energy Policy 2011;39(5):2299–309.
[28] Crosbie T. Household energy consumption and consumer electronics: the case of television. Energy Policy 2008;36(6):2191–9.
[29] Wall R, Crosbie T. Potential for reducing electricity demand for lighting in households: an exploratory socio-technical study. Energy Policy 2009;37(3):1021–31.
[30] Abrahamse W, Steg L. How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? Journal of Economic Psychology 2009;30(5):711–20.
[31] Wang Z, Zhang B, Yin J, Zhang Y. Determinants and policy implications for household electricity-saving behaviour: evidence from Beijing, China. Energy Policy 2011;39(6):3550–7.
[32] Steg L, Vlek C. Encouraging pro-environmental behaviour: an integrative review and research agenda. Journal of Environmental Psychology 2009;29(3):309–17.
[33] Breukers SC, Heiskanen E, Brohmann B, Mourik RM, Feenstra CFJ. Connecting research to practice to improve energy demand-side management (DSM). Energy 2011;36(4):2176–85.
[34] Wilson C, Dowlatabadi H. Models of decision making and residential energy use. Annual Review of Environment and Resources 2007;32: 169–203.
[35] Burgess J, Nye M. Changing energy-related behavior: an intervention mapping approach. Energy Policy 2011;39(9):5280–6.
[36] Burgess J, Nye M. Re-materialising energy use through transparent monitoring systems. Energy Policy 2008;36(12):4454–9.
[37] Karjalainen S. Consumer preferences for feedback on household electricity consumption. Energy and Buildings 2011;43(2–3):458–67.
[38] Wood G, Newborough M. Influencing user behaviour with energy information display systems for intelligent homes. International Journal of Energy Research 2007;31(1):56–78.
[39] Wood G, Newborough M. Energy-use information transfer for intelligent homes: enabling energy conservation with central and local displays. Energy and Buildings 2007;39(4):495–503.
[40] Schleich J, Gruber E. Beyond case studies: barriers to energy efficiency in commerce and the services sector. Energy Economics 2008;30(2):449–64.
[41] Schleich J. Barriers to energy efficiency: a comparison across the German commercial and services sector. Ecological Economics 2009;68(7):2150–9.
[42] Chung W, Hui YV. A study of energy efficiency of private office buildings in Hong Kong. Energy and Buildings 2009;41(6):696–701.
[43] Mairet N, Decellas F. Determinants of energy demand in the French service sector: a decomposition analysis. Energy Policy 2009;37(7):2734–44.
[44] Yu PCH, Chow WK. Energy use in commercial buildings in Hong Kong. Applied Energy 2001;69(4):243–55.
[45] Carrico AR, Riemer M. Motivating energy conservation in the workplace: an evaluation of the use of group-level feedback and peer education. Journal of Environmental Psychology 2011;31(1):1–13.
[46] Karjalainen S. Thermal comfort and use of thermostats in Finnish homes and offices. Building and Environment 2009;44(6):1237–45.
[47] de Almeida A, Fonseca P, Schlomann B, Feilberg N. Characterization of the Household Electricity Consumption in the EU: potential energy savings and specific policy recommendations. Energy and Buildings 2011;43(8):1884–94.
[48] Ouyang J, Hokao K. Energy-saving potential by improving occupants' behavior in urban residential sector in Hangzhou City: China. Energy and Buildings 2009;41(7):711–20.
[49] Al-Mumin A, Khattab O, Sridhar G. Occupants' behavior and activity patterns influencing the energy consumption in the Kuwaiti residences. Energy and Buildings 2003;35(6):549–59.
[50] Dietz T, Gardner GT, Gilligan J, Stern PC, Vandenbergh MP. Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. Proceedings of the National Academy of Sciences 2009;106(44):18452–6.
[51] Faruqui A, Sergici S, Sharif A. The impact of informational feedback on energy consumption—a survey of the experimental evidence. Energy 2010;35(4):1598–608.
[52] Masoso OT, Grobler LJ. The dark side of occupants' behaviour on building energy use. Energy and Buildings 2010;42(2):173–7.

[53] Webber CA, Roberson JA, McWhinney MC, Brown RE, Pinckard MJ, Busch JF. After-hours power status of office equipment in the USA. Energy 2006;31(14):2823–38.
[54] Granderson J, Piette M, Ghatikar G. Building energy information systems: user case studies. Energy Efficiency 2011;4(1):17–30.
[55] Lutzenhiser L, Moezzi M, Hungerford D, Friedmann R. Sticky points in modeling household energy consumption. In: ACEEE summer study on energy efficiency in buildings. Pacific Grove, CA: ACEEE; 2010.
[56] Gillingham K, Newell RG, Palmer KL. Energy efficiency economics and policy. NBER Working Paper Series; 2009. w15031.
[57] Rogers EM. Diffusion of innovations. 5th Revised ed. Simon & Schuster International; 2003.
[58] Thøgersen J, Grønhøj A. Electricity saving in households – a social cognitive approach. Energy Policy 2010;38(12):7732–43.
[59] Richardson I, Thomson M, Infield D, Clifford C. Domestic electricity use: a high-resolution energy demand model. Energy and Buildings 2010;42(10):1878–87.
[60] Widén J, Lundh M, Vassileva I, Dahlquist E, Ellegård K, Wäckelgård E. Constructing load profiles for household electricity and hot water from time-use data – modelling approach and validation. Energy and Buildings 2009;41(7):753–68.
[61] Yu Z, Fung BCM, Haghighat F, Yoshino H, Morofsky E. A systematic procedure to study the influence of occupant behavior on building energy consumption. Energy and Buildings 2011;43(6.).
[62] Faiers A, Cook M, Neame C. Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use. Energy Policy 2007;35(8):4381–90.
[63] Swan LG, Ugursal VI. Modeling of end-use energy consumption in the residential sector: a review of modeling techniques. Renewable and Sustainable Energy Reviews 2009;13(8):1819–35.
[64] Kavgic M, Mavrogianni A, Mumovic D, Summerfield A, Stevanovic Z, Djurovic-Petrovic M. A review of bottom-up building stock models for energy consumption in the residential sector. Building and Environment 2010;45(7):1683–97.
[65] Isaksson C, Karlsson F. Indoor climate in low-energy houses – an interdisciplinary investigation. Building and Environment 2006;41(12):1678–90.
[66] Pino FE, Herde Ad. Definition of occupant behaviour patterns with respect to ventilation for apartments from the real estate market in Santiago de Chile. Sustainable Cities and Society 2011;1(1):38–44.
[67] Andersen RV, Toftum J, Andersen KK, Olesen BW. Survey of occupant behaviour and control of indoor environment in Danish dwellings. Energy and Buildings 2009;41(1):11–6.
[68] Roetzel A, Tsangrassoulis A, Dietrich U, Busching S. A review of occupant control on natural ventilation. Renewable and Sustainable Energy Reviews 2010;14(3):1001–13.
[69] Yun GY, Steemers K. Behavioural: physical and socio-economic factors in household cooling energy consumption. Applied Energy 2011;88(6): 2191–200.
[70] Santin OG, Itard L, Visscher H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings 2009;41(11):1223–32.
[71] Hoes P, Hensen JLM, Loomans MGLC, Vries Bd, Bourgeois D. User behavior in whole building simulation. Energy and Buildings 2009;41(3):295–302.
[72] Toftum J, Andersen RV, Jensen KL. Occupant performance and building energy consumption with different philosophies of determining acceptable thermal conditions. Building and Environment 2009;44(10):2009–16.
[73] Santin OG. Behavioural patterns and user profiles related to energy consumption for heating. Energy and Buildings 2011;43(10):2662–72.
[74] Stamminger R. Modelling resource consumption for laundry and dish treatment in individual households for various consumer segments. Energy Efficiency 2011:1–11.
[75] Jian L, Ng SKK, Kendall G, Cheng JWM. Load signature study. Part II: disaggregation framework, simulation, and applications. IEEE Transactions on Power Delivery 2010;25(2):561–9.
[76] Cena K, Dear Rd. Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. Journal of Thermal Biology 2001;26(4–5):409–14.
[77] Haldi F, Robinson D. On the behaviour and adaptation of office occupants. Building and Environment 2008;43(12):2163–77.
[78] Pfafferott J, Herkel S. Comparison of low-energy office buildings in summer using different thermal comfort criteria. Energy and Buildings 2007;39(7):750–7.
[79] Saelens D, Parys W, Baetens R. Energy and comfort performance of thermally activated building systems including occupant behavior. Building and Environment 2011;46(4):835–48.
[80] Wagner A, Gossauer E, Moosmann C, Gropp T, Leonhart R. Thermal comfort and workplace occupant satisfaction – results of field studies in German low energy office buildings. Energy and Buildings 2007;39(7):758–69.
[81] Voss K, Herkel S, Pfafferott J, Löhnert G. Energy efficient office buildings with passive cooling – results and experiences from a research and demonstration programme. Solar Energy 2007;81(3):424–34.
[82] Yun GY, Tuohy P, Steemers K. Thermal performance of a naturally ventilated building using a combined algorithm of probabilistic occupant behaviour and deterministic heat and mass balance models. Energy and Buildings 2009;41(5):489–99.
[83] Herkel S, Knapp U, Pfafferott J. Towards a model of user behaviour regarding the manual control of windows in office buildings. Building and Environment 2008;43(4):588–600.
[84] Kolokotsa D, Rovas D, Kosmatopoulos E, Kalaitzakis K. A roadmap towards intelligent net zero – and positive – energy buildings. Solar Energy 2011;85(12):3067–84.
[85] Pfafferott J, Herkel S. Statistical simulation of user behaviour in low-energy office buildings. Solar Energy 2007;81(5):676–82.
[86] Zhang T, Siebers P-O, Aickelin U. Modelling electricity consumption in office buildings: an agent based approach. Energy and Buildings 2011;43(10):2882–92.
[87] Goldblatt DL, Hartmann C, Dürrenberger G. Combining interviewing and modeling for end-user energy conservation. Energy Policy 2005;33(2):257–71.
[88] Seem JE. Pattern recognition algorithm for determining days of the week with similar energy consumption profiles. Energy and Buildings 2005;37(2):127–39.
[89] Crosbie T. Household energy studies: the gap between theory and method. Energy & Environment 2006;17(5):735–53.